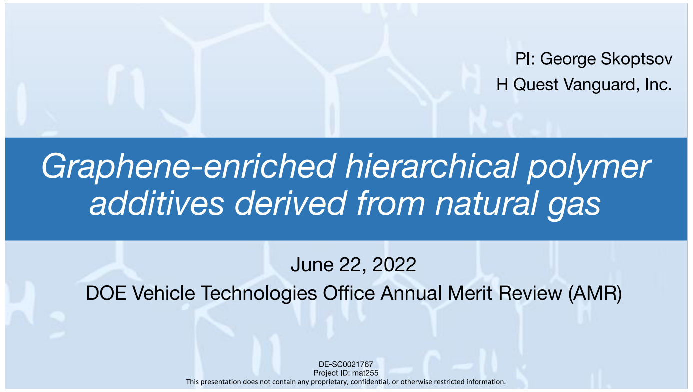
Graphene-Enriched Hierarchical Polymer Additives Derived From Natural Gas

PI: George Skoptsov | H Quest Vanguard, Inc., Pittsburgh, PA | DE-SC0021767 | MAT255



Overview

Timeline and Budget

Project start date: 08/04/2021
Project end date: 06/23/2022
Total funding: $206,500
Percent complete: 80%

Barriers and Technical Targets

Material Technical Team Technical Targets:

- 50% mass reduction @ equal affordability (stretch objective long-term)
- USDRIVE Target 2025* – 25% weight reduction (Glider) < $5/lb

Partners and Collaborations

Project Lead: H Quest Vanguard, Inc.
PI: George Skoptsov

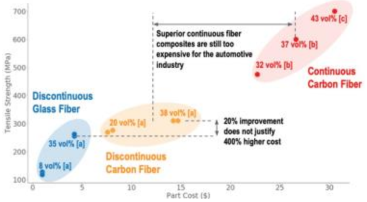
Collaborator/Sub: Penn State University
Dr. Randy Vander Wal

Commercialization support: Composites Applications Group
In-kind support: Carbon Conversions, Inc. *(provided samples of rCF)*

Relevance

Objective

Enable mass production of low-cost reinforced automotive composites via improving interfacial characteristics of chopped recycled carbon fiber.



Innovations

- Novel approach enabling rapid (< 5 sec) upgrading of chopped carbon fiber via separation, etching, and decoration in a single microwave plasma process.
- Demonstrated applicability to other solid carbon materials, e.g. upgrading of carbon black from tire recycling processes.

Impacts

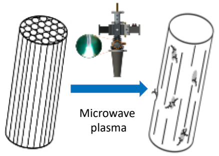
- 10x increase in surface area translates into significant interfacial strength increase for the chopped recycled carbon fibers.
- Stronger low-cost compression-molded composite parts promise further advances in automotive lightweighting.
- Applicability to a broad range of carbon materials encourages circularity and waste reduction in the automotive industry.

Technical Approach

Key idea: Rapidly process chopped recycled carbon fiber in a microwave plasma reactor to improve interfacial strength in low-cost thermoplastic composites.

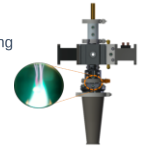
Process: Thermochemical process first etches and roughens the fiber surface and then deposits high-surface area carbons hybridized with crumpled graphene sheets.

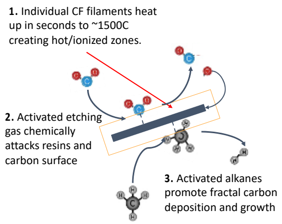
Impact: Targeted tensile strength improvements of 70%-100% would enable low-cost injection-molded composite parts to meet price-performance requirements of automotive industry.



Microwave plasma: rapid thermochemical process

- Rapid volumetric heating
- Continuous, high-throughput processing
- Instant start-up/shut-down
- No process CO_2 emissions
- Flexibility in feedstocks and products
- Compact, low-capital deployment





Summary

The demonstrated approach can significantly improve mechanical properties of thermoplastic resins with use of a novel hierarchical, hybrid reinforcement filler (HHF).

The multi-scale surface of a recycled carbon fibers (rCF) is decorated with a high structure, graphene-enriched carbon black (GCB) to dramatically improve the short fibers interfacial and inter-laminar shear strength metrics in low-cost thermoplastic resins.

H Quest previously demonstrated standalone GCB as a novel carbon nano-additive, synthesized from gaseous hydrocarbon feedstocks (methane or higher alkanes) in a microwave plasma pyrolysis.

Unlike other carbon nano-additives such as nanotubes or graphene sheets, production of which requires use of catalysts and a slow surface vapor deposition process, GCB is formed rapidly (order of microseconds[1]) and volumetrically in gas phase. This enables continuous, high-throughput, low-cost processing ($0.25/kg before cost of equipment).

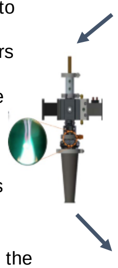
The compounded effects of hybridizing the chopped carbon fiber with GCB would significantly exceed those of sizings or nanoparticle additives.

The significant increase in ultimate tensile strength (targeted 70%- 100%) of the rCF-reinforced thermoplastic parts without significant increase in cost is envisioned to enable adoption by the automotive industry, promote lightweighting, and improve circularity of carbon fiber materials.

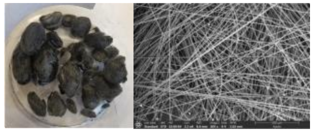
Accomplishments

Near-instantaneous exposure to microwave plasma heats chopped recycled carbon fibers to ~1500C and thermochemically modifies the surface, separating filaments, gently etching them, and depositing nanoscale high-surface area carbon structures with graphenic components.

Overall, the process increases the carbon fiber surface area by ~ 10x as measured by BET.

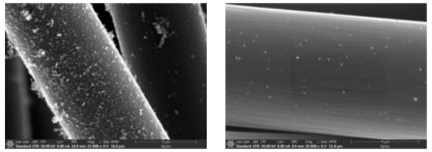


As-received chopped recycled carbon fiber. Filaments are strongly aligned and stuck together, reducing surface area and suppressing resin



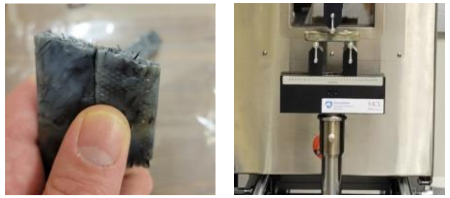
Same fiber after only a few seconds of processing. Thermochemical treatment removes remaining resin, and separates, etches, and decorates individual filaments

Accomplishments



Control over gas feeds and plasma allows tuning the density of high-structure carbon deposition on the carbon fiber surface.

Tests with thermoplastic polymers (HDPE) are ongoing; preliminary results indicate that the gained interfacial strength exceeds tensile strength of the filaments

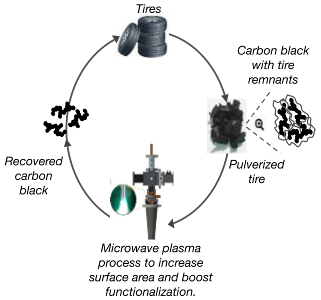


Future Scope Expansion

Improve circularity of automotive tires.
Microwave plasma treatment to restore the reinforcement properties of recycled carbon blacks (rCBs) by removal of polymer remnants and surface functionalization.

Recycled carbon blacks (along with polymers, process aids, and fillers) are recovered after pyrolysis of end-of-life tires compounds.

Tire pyrolysis changes the surface chemistry of the original carbon black, reducing reinforcement properties. Today, rCB cannot replace virgin carbon blacks.



Future Steps

Scale-up the microwave plasma treatment system and process

Increase capacity from < 20 g to > 1 kg
Make continuous rather than batch processing
Establish process-product parameter relationships

Scale-up composite preparation and properties evaluation

Systematic evaluation of composite properties and repeatability/consistency at lab scales (>1 kg) across multiple low-cost thermoplastics (HDPE, Nylon, etc).
Evaluate and optimize fiber / composite property relationships

Pilots with carbon fiber and composite companies

Secure technology commercialization paths
Contract revenues and R&D synergies